

EFFECTS OF FLY ASH, MAIZECOB ASH, AND GROUNDNUT SHELL ASH ON THE PROPERTIES OF SELF-COMPACTING GEOPOLYMER CONCRETE WITH GGBS BLEND

Abstract

Concrete stands as the ubiquitous human-made construction material worldwide, with ordinary Portland cement (OPC) being a fundamental component in conventional concrete mixes. However, the production of cement is associated with the release of carbon dioxide emissions. As responsible citizens Engineers and scientists are allowed to create a more sustainable world, by developing the practices of using a green building material. Geopolymer can be considered as the solution which can be produced without OPC and contributes less release of greenhouse gasses. Also, the performance of hardened concrete characteristics like surface quality, strength, and durability has been enhanced using self-compacting geopolymer concrete (SCGPC) technology. The key objective of this study was to examine how different ashes, such as fly ash (FA), maize cobash (MCBA), and groundnut shell ash (GSA), affected the blended SCGPC composed of ground granulated blast furnace slag (GGBS). In this study, the ratios of GGBS and ash used to make SCGPC were maintained at 50%:50%. Both SCGPC's fresh and hardened characteristics were identified. All ashes performed well, although FA and GGBS blended SCGPC blends were the best in both the fresh and hardened stages. Further, in this study, the experimental splitting tensile strength of SCGPC was compared to the predicted values from ACI 363R and CEB-FIP. The experimental SCGPC modulus of elasticity was compared to the expected values from ACI 363R and ACI 318.

Keywords: Fly Ash, Maize Cob Ash, Groundnut Shell Ash, Compressive Strength; Portland Cement, Carbon Dioxide.

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I. INTRODUCTION

On the planet after water the most widely used material was Concrete. About 4.5 percent of carbon dioxide was emitted because of manufacturing concrete [1]. Geopolymer concrete is a unique improvement in construction technology due to its use of industrial waste and by-products. This novel approach is gaining popularity as an eco-friendly building material with the potential for sustainable development. In this instance, geopolymer concrete substitutes slag and alkali components for the conventional usage of ordinary Portland cement (OPC) as a binding agent. These materials have many benefits over OPC, one of which is a significant decrease in CO₂ emissions related to cement production. Additionally, this approach contributes in the efficient reuse of agricultural wastes including groundnut shell ash, rice husk ash, bagasse ash, and maizecob ash as well as industrial wastes like fly ash and slag.

A significant application of geopolymer concrete involves its integration as a self-compacting variant, presenting the opportunity to eliminate the need for manual compaction during construction processes, particularly in densely populated areas. Notably, Ground Granulated Blast Furnace Slag (GGBS), a by-product resulting from iron-making blast furnaces, plays a pivotal role in this technology. GGBS is generated during the iron production process, subsequently undergoes drying, and is then finely ground to achieve a powder-like consistency. This utilization of GGBS in geopolymer concrete showcases a comprehensive approach towards resource optimization and environmental stewardship within the construction domain. [2].

The polymerization process exhibits heightened rates when conducted at elevated temperatures relative to ambient conditions. Geopolymer derived from fly ash, which is synthesized at ambient temperatures, initially demonstrates lower compressive strength in comparison to heat-cured specimens. However, in the case of ambient curing, the compressive strength experiences a notable augmentation as the concrete ages from 7 days to 28 days. Contrarily, the compressive strength of fly ash-based geopolymer concrete subjected to high-temperature curing displays limited growth beyond the 7-day mark. Additionally, it is worth noting that the tensile strength of geopolymer concrete displays an ascending trend with an increase in the overall aggregate content [3].

From a practical standpoint, establishing ambient temperature conditions assumes paramount importance. Consequently, this investigation aims to develop geopolymer concrete utilizing fly ash and ground granulated blast slag, with the primary objective of enhancing its engineering properties.

II. EXPERIMENTAL STUDY

Materials: In this study, Class F fly ash and GGBS (Ground Granulated Blast Furnace Slag) were employed as substitutes for conventional cementitious materials, constituting 75-80% of the total concrete mass. It is worth noting that Geopolymer Concrete (GC) can be formulated using various source materials. The subsequent sections provide detailed insights into the properties of the primary ingredients utilized in the creation of Self-Compacting Geopolymer Concrete (SGPC), encompassing both their chemical and physical attributes. The components typically utilized in the formulation of SGPC include:

- Discarded ashes, which encompass fly ash, maize cob ash, and groundnut shell ash.
 - GGBS, commonly referred to as ground granulated blast furnace slag.
 - Fine aggregates, specifically M-Sand.
 - Coarse aggregates.
 - An alkaline liquid.
1. **Discarded Ashes:** The study utilized Class F fly ash sourced from the Rayalaseema Thermal Power Plant (RTPP) located in Muddanur, Andhra Pradesh. The selection of this fly ash followed the guidelines outlined in ASTM C 618 (2003). Notably, the specific gravities of the locally accessible materials, namely FA (fly ash), MCBA (maize cob ash), and GSA (groundnut shell ash), were determined to be 2.11, 1.85, and 2.06, respectively, as referenced in [4].
 2. **Ground Granulated Blast Furnace Slag (GGBS):** In this current research, GGBS (Ground Granulated Blast Furnace Slag) sourced from the Vizag steel plant was employed in the production of Geopolymer Concrete (GPC). The specific gravity of GGBS was determined to be 2.85, as documented in [5].
 3. **Fine Aggregate (M-Sand):** Fine aggregate in the form of natural river sand was incorporated. The bulk specific gravity and water absorption characteristics of the sand were assessed in accordance with IS 2386 (part III, 1963), resulting in values of 2.62 and 1%, respectively. The sand's fineness modulus was measured to be 2.69.
 4. **Coarse Aggregate:** Coarse aggregates in the form of crushed granite stones, each with a size of 12.5mm, were employed in the study. The bulk specific gravity of these aggregates under oven-dry conditions and their water absorption properties, as per IS 2386 (part III, 1963), were determined to be 2.58 and 0.3%, respectively.
 5. **Alkaline Liquid:** It is utilized in conjunction with a combination of sodium silicate solution and sodium hydroxide solution. The sodium silicate solution, with a composition of Na₂O at 13.7%, SiO₂ at 29.4%, and water at 55.9%, was procured from a local supplier. Sodium hydroxide (NaOH) was obtained either in flake or pellet form and dissolved in water. The quantity of NaOH solids present in the solution varied based on the solution's concentration, expressed in terms of molarity (M). For instance, a 10M NaOH solution contained 400 grams of NaOH solids (in flake or pellet form) per liter of the solution, where 40 represent the molecular weight of NaOH.

III. MATERIALS MIX PROPORTIONS

Drawing from the restricted body of prior research on SGPC, the following hypotheses emerged subsequent to conducting trial blends for the components within the mixtures, as documented in [6].

Table 1: GPC Mix Propositions

Materials		Mass (kg/m ³)		
		FA50- GGBS50	MCBA50- GGBS50	GSA50- GGBS50
Coarse aggregate	12.5 mm	780	780	780
Fine aggregate		886	886	886
Waste Ashes		214.5	214.5	214.5
GGBS		214.5	214.5	214.5
Sodium silicate solution		102	102	102
Sodium hydroxide solution		41(10M)	41(10M)	41(10M)
Extra water		56	56	56
Alkaline Solution (FA+GGBS) (by weight)		0.35	0.35	0.35
Water/ geopolymer solids (by weight)		0.29	0.29	0.29

1. Manufacture of Test Specimen

- Preparation of Alkaline Liquid:** Within this investigation, a solution of NaOH solids was prepared by dissolving 400 grams of NaOH pellets (where 40 denote the molecular weight of NaOH) in 600 milliliters of water. This resulted in the formulation of one liter of NaOH solution with a concentration of 10 M. Notably, the sodium hydroxide solution was blended together one day in advance before its intended utilization.
- Manufacture of Fresh Concrete:** The aggregates were prepared under saturated surface-dry (SSD) conditions. The process involved mixing waste ash, GGBS, and aggregates for approximately 3 minutes. Following this, 70% of additional water was introduced into the mixture and mixed for one minute. Subsequently, the alkaline liquid was added along with the remaining 30% of extra water, and the mixture was thoroughly blended for about 2 minutes. The resulting fresh concrete was then cast and molded using conventional methods employed for Portland cement [7&8]. It's worth noting that the fresh waste ash and GGBS-blended geopolymer concrete exhibited good cohesion. To assess its workability, compliance with EFNARC guidelines was employed, encompassing evaluations of segregation, passage, and flowability [9&110].
- Curing of Test Specimens:** Following casting and demoulding, the test specimens were subjected to curing at the ambient room temperature conditions until the commencement of the testing phase on these specimens [11,&12].

- Compressive Strength Test:** The compressive strength testing was performed on cubical specimens for all the mixtures after curing for 7, 14, and 28 days [13&4]. For each age

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and mix, three cubical specimens, each measuring 150mm x 150mm x 150mm, were cast and subjected to testing [15 & 16]. The compressive strength (f_c) of each specimen was determined by dividing the maximum load applied to the specimen by the cross-sectional area of the specimen.

- 3. Split Tensile Strength Test:** The split tensile strength (STS) test was conducted on the specimens for all mixtures after 28 days of curing, following the IS 5816 (1999) standard [17]. For each age and mix, three cylindrical specimens measuring 150 mm in diameter and 300 mm in length were cast and subjected to testing. The load was applied gradually until the specimen failed, and the maximum load applied was recorded [18&19]. The length and cross-sectional diameter of each specimen were measured. The splitting tensile strength (f_{ct}) was then calculated using the following formula:

$$f_{ct} \text{ (N/mm}^2\text{)} = 2P / (\pi * l * d)$$

Where:

P = Maximum load applied to the specimen (in Newton)

l = Length of the specimen (in mm)

d = Cross-sectional diameter of the specimen (in mm)

IV. RESULTS AND DISCUSSION

- 1. Fresh Properties of SGPC:** Table 2 displays the mechanical properties of Self-Compacting Geopolymer Concrete (SGPC) mixtures, specifically those comprised of varying combinations such as FA 50 - GGBS 50, MCBA 50 - GGBS 50, and GSA 50 - GGBS 50.

Table 2: Fresh Properties of SGPC

Fresh Properties	Acceptance Criteria as per EFNARC	Mix Type		
		FA50 – GGBS 50	MCBA50 – GGBS50	GSA50 – GGBS 50
Slump Flow (mm)	650-800	786	724	695
T_{50cm} (sec)	3-5	3.56	4.04	4.78
V-funnel Time (sec)	6-12	8.14	9.18	11.26
L-box Ratio(h_2/h_1)	0.80-1.00	0.90	0.92	0.83
U-box(mm)	0-30	11.20	16.30	18.10

Table 2 indicates that the SGPC mix with FA50 - GGBS 50 exhibits superior fresh properties when compared to the MCBA50 - GGBS50 and GSA50 - GGBS 50 mixtures.

- 2. Mechanical Properties of SGPC:** Table 3 provides an overview of the mechanical properties of SGPC mixtures (FA 50 - GGBS 50, MCBA 50 - GGBS 50, GSA 50 - GGBS 50) at various curing durations or periods.

Table 3: Mechanical Properties of SGPC

Mechanical Property	Age (Days)	Mix Type		
		FA50 – GGBS 50	MCBA50 – GGBS50	GSA50 – GGBS 50
Compressive strength , f'_c (N/mm ²)	7	39.8	38.6	36.6
	14	46.9	44.0	41.5
	28	53.0	50.5	46.5
Split tensile strength , f'_{ct} (N/mm ²)	7	1.50	1.32	1.10
	14	2.22	2.05	1.80
	28	3.26	3.15	2.90

The results reveal that the FA50 - GGBS 50 mixture achieved a compressive strength of 39.8N/mm² after 7 days of curing itself. The mix MCBA50 –GGBS50 has attained slightly lower compressive strength of 38.6N/mm² when compared to the mix FA50 – GGBS 50 after 7 days of curing. The mix GSA50 – GGBS 50 has attained lower compressive strength of 36.6 N/mm² when compared to both of FA50 – GGBS 50 and MCBA50 –GGBS50 after 7days of curing. Similarly,FA50 – GGBS 50 has achieved a compressive strength of 46.9N/mm² after 14 days of curing itself [20]. The mix MCBA50 –GGBS50 has attained slightly lower compressive strength of 44.0N/mm² when compared to the mix FA50 – GGBS 50 after 14 days of curing. The mix GSA50 – GGBS 50 has attained lower compressive strength of 41.5 N/mm² when compared to both of FA50 – GGBS 50 and MCBA50 –GGBS50 after 14days of curing and FA50 – GGBS 50 has attained compressive strength of 53.0N/mm² after28 days of curing itself. The mix MCBA50 –GGBS50 has attained slightly lower compressive strength of 50.5N/mm² when compared to the mix FA50 – GGBS 50 after 28 days of curing. The mix GSA50 – GGBS 50 has attained lower compressive strength of 46.5 N/mm² when compared to those of FA50 – GGBS 50 and MCBA50 –GGBS50 after 28days of curing.

The results clearly indicate that SGPC mixes incorporating GGBS in combination with FA have consistently achieved higher compressive strength values at all tested ages when compared to GPC mixes that employ MCBA and GSA (MCBA50 - GGBS50 and GSA50 - GGBS50). These findings are graphically represented in Figure 1.

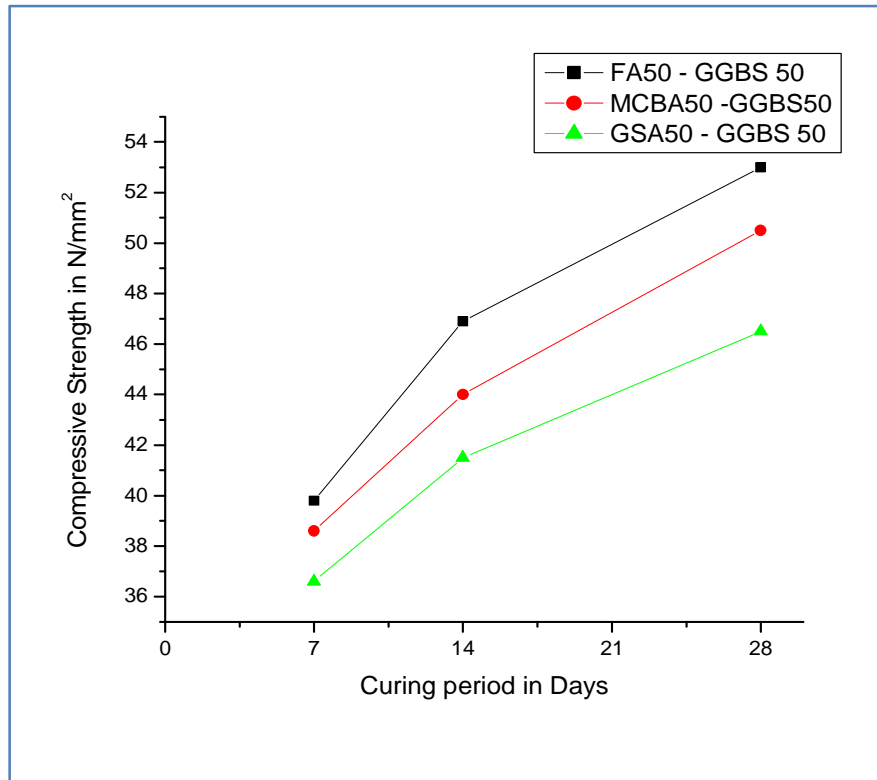


Figure 1: Compressive Strength of Concrete

The results indicate that the FA50 - GGBS 50 mixture achieved a splitting tensile strength (STS) of 1.50 N/mm² after 7 days of curing. The mix MCBA50 -GGBS50 has attained slightly lower STS of 1.32N/mm² when compared to the mix FA50 - GGBS 50 after 7 days curing. The mix GSA50 - GGBS 50 has attained lower STS of 1.10N/mm² when compared to FA50 - GGBS 50 and MCBA50 -GGBS50 after 7 days curing.

Similarly, FA50 - GGBS 50 has attained splitting tensile (STS) of 2.20 N/mm² after 14 days of curing. The mix MCBA50 -GGBS50 has attained slightly lower STS of 2.05 N/mm² when compared to the mix FA50 - GGBS 50 after 14 days curing. The mix GSA50 - GGBS 50 has attained lower STS of 1.80 N/mm² when compared to FA50 - GGBS 50 and MCBA50 -GGBS50 after 14 days curing and FA50 - GGBS 50 has attained splitting tensile (STS) of 3.26 N/mm² after 28 days of curing. The mix MCBA50 -GGBS50 has attained slightly lower STS of 3.15 N/mm² when compared to the mix FA50 - GGBS 50 after 28 days curing. The mix GSA50 - GGBS 50 has attained lower STS of 2.90 N/mm² when compared to FA50 - GGBS 50 and MCBA50 -GGBS50 after 28 days curing. The results are graphically presented in Figure 2.

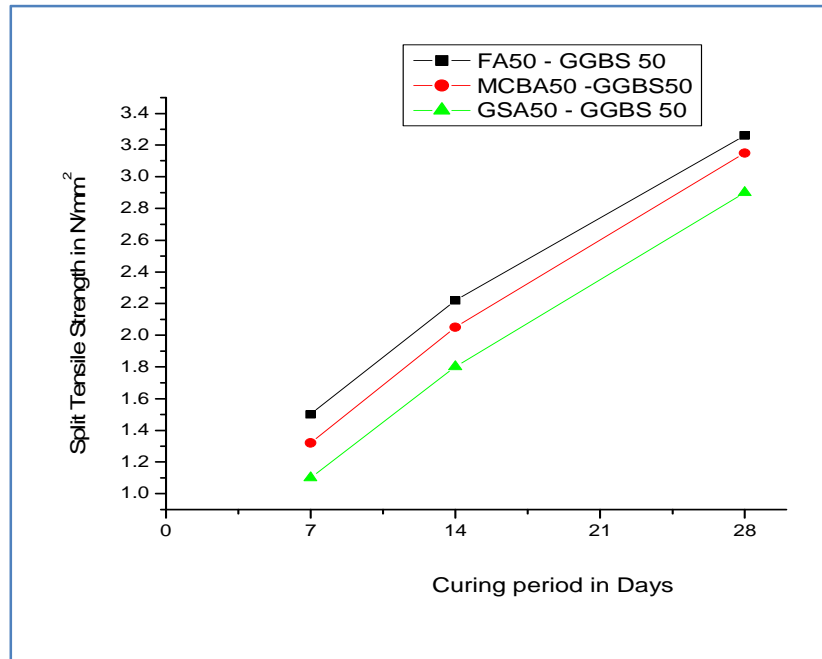


Figure 2: Split Tensile Strength

V. CONCLUSIONS

Based on the outcomes presented in this study, the following conclusions can be deduced:

1. Irrespective of the mix proportions, both compressive strength and split tensile strength of the Self Compacting Geopolymer Concrete exhibit a consistent increase with the duration of curing.
2. The FA 50 - GGBS 50 mixture consistently demonstrates the highest compressive strength and split tensile strength among the various mix combinations, regardless of the curing period.
3. The early stage (7 days) shows a notable rapid increase in compressive strength and split tensile strength for the Self Compacting Geopolymer Concrete; however, this rate of strength gain decreases as the curing period extends.
4. The findings suggest that Geopolymer concrete holds promise as an innovative construction material with potential applications in the construction industry.

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